CHAPTER 5

DESIGN CONSIDERATIONS

Section I. Control Works

5-1. Purpose. Control works are constructed in estuaries to confine channels to definite alignments, reduce or relocate shoaling, reduce wave action in harbor areas, improve navigation conditions, prevent or reduce salinity intrusion, or prevent or reduce flooding.

5-2. Types. The principal types of control works in estuaries are as follows:

a. Breakwaters. These structures are partial barriers at the entrance to embayments, coves, or channels in water subject to severe wave action for the purpose of providing shelter from waves. Examples are shown in Figure 5-1.

b. Training Dikes. Training dikes may be longitudinal structures extending along the course of the waterway in a critical reach, or alternatively a series of structures extending out from the shore generally perpendicular to the currents to guide or direct the currents, reduce channel shoaling, or prevent bank erosion. Examples are shown in Figure 5-2.

c. Salinity Barriers. One type is a dam that extends completely across the waterway to exclude saline waters from upstream areas. This type necessarily includes spillways to discharge flows from the upland, and often one or more sets of locks to permit vessels to navigate beyond the barrier. An example of this type of salinity barrier is shown in Figure 5-3. Another type of salinity barrier is the submerged sill. This type is intended to reduce salinity intrusion by disrupting the bottom salinity wedge as it intrudes upstream or to induce vertical mixing of the salt and fresh waters. The sill can be permanent, constructed of stone or other permanent material, or temporary, constructed of sand. A sketch of this type of barrier is shown in Figure 5-4.

d. Hurricane Barriers. Hurricane barriers are structures that extend completely across the waterway, except for gaps at navigation channels. The purpose of hurricane barriers is to reduce the magnitude of hurricane surges upstream of the barrier. An example is shown in Figure 5-5.

e. Revetments. Revetments are constructed along the banks of the waterway to prevent erosion by currents and waves. An example is shown in Figure 5-6.

f. Diversion Works. These works intercept freshwater discharges from upland areas and cause them to be discharged to sea using an adjacent waterway. An example is shown in Figure 5-7.

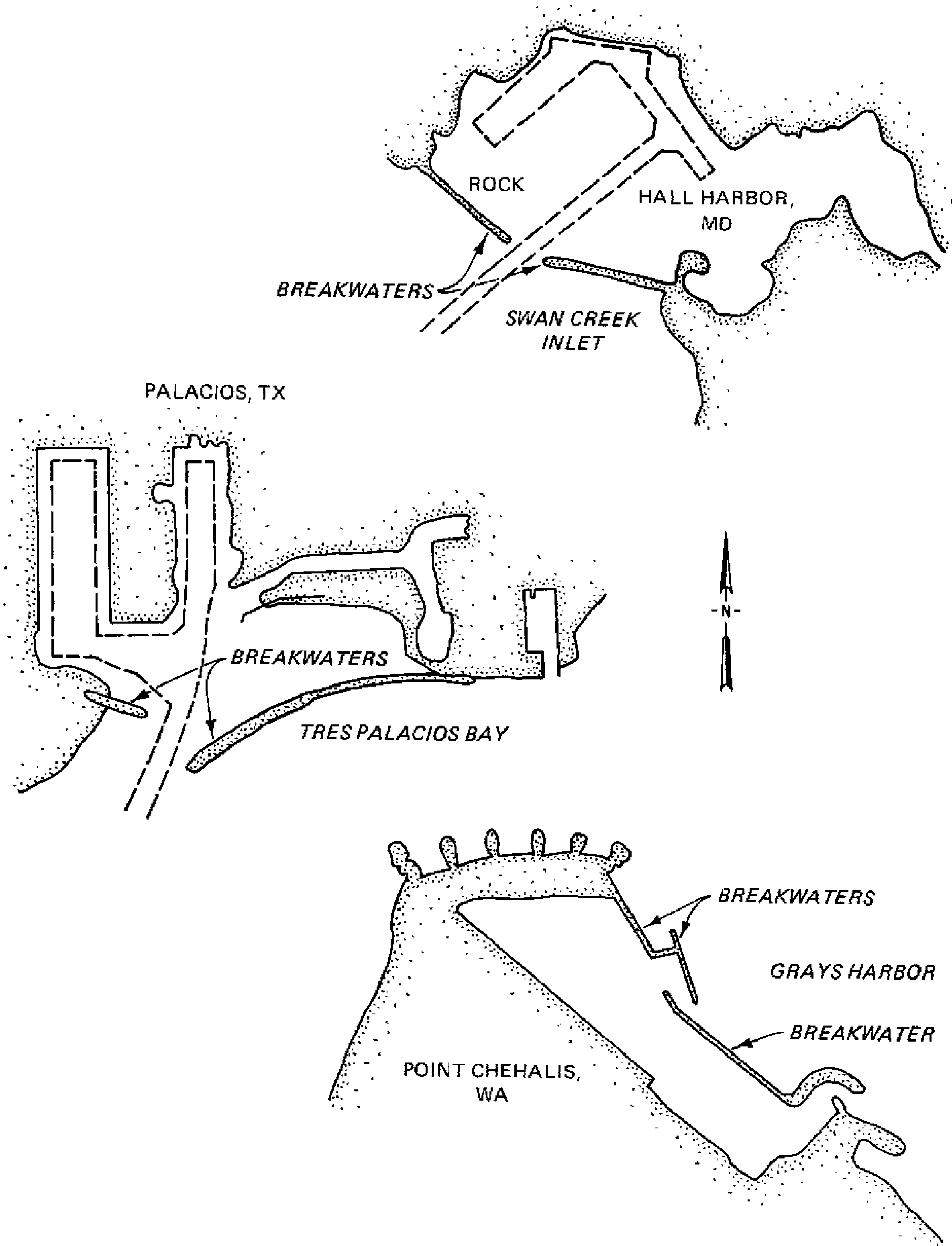


Figure 5-1. Estuarine breakwaters

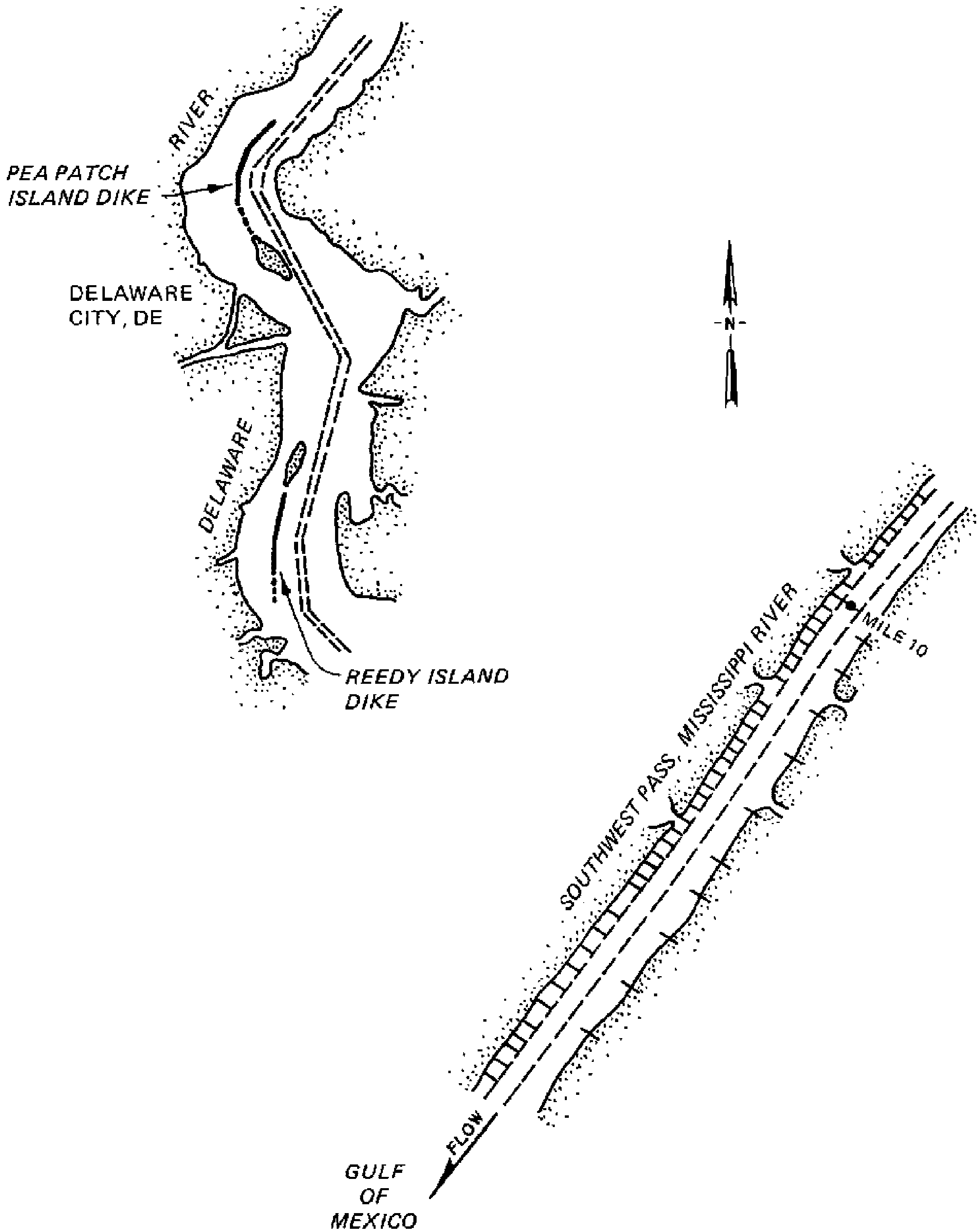
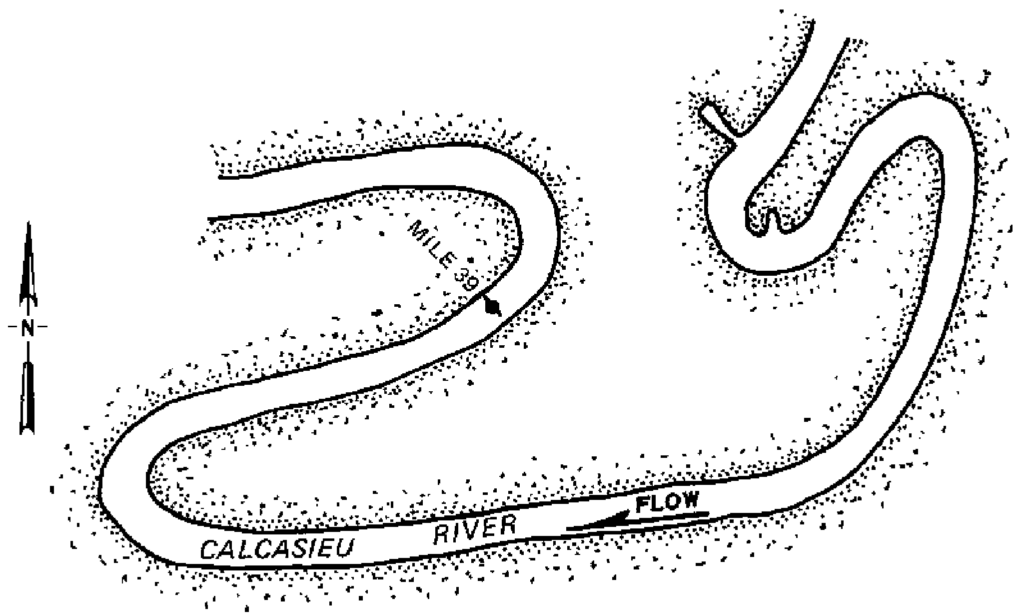
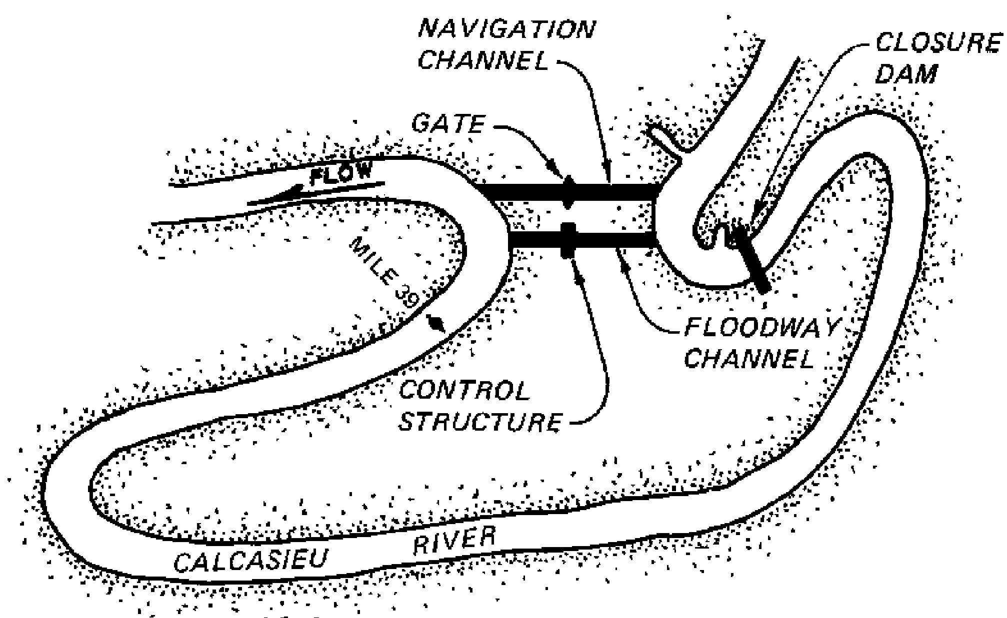


Figure 5-2. Training dikes



a. MEANDER PRIOR TO CONSTRUCTION



b. MEANDER WITH SALINITY BARRIER IN PLACE

Figure 5-3. Salinity barrier structure

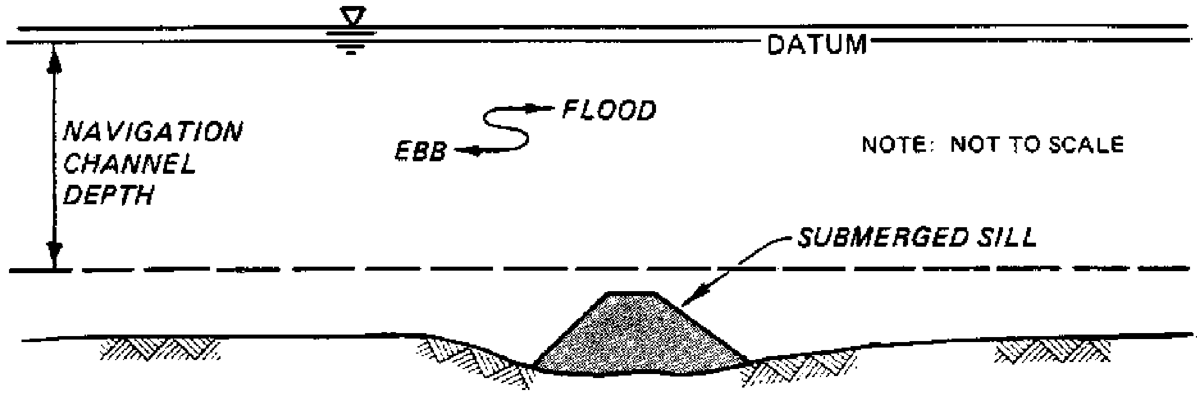


Figure 5-4. Submerged sill salinity barrier

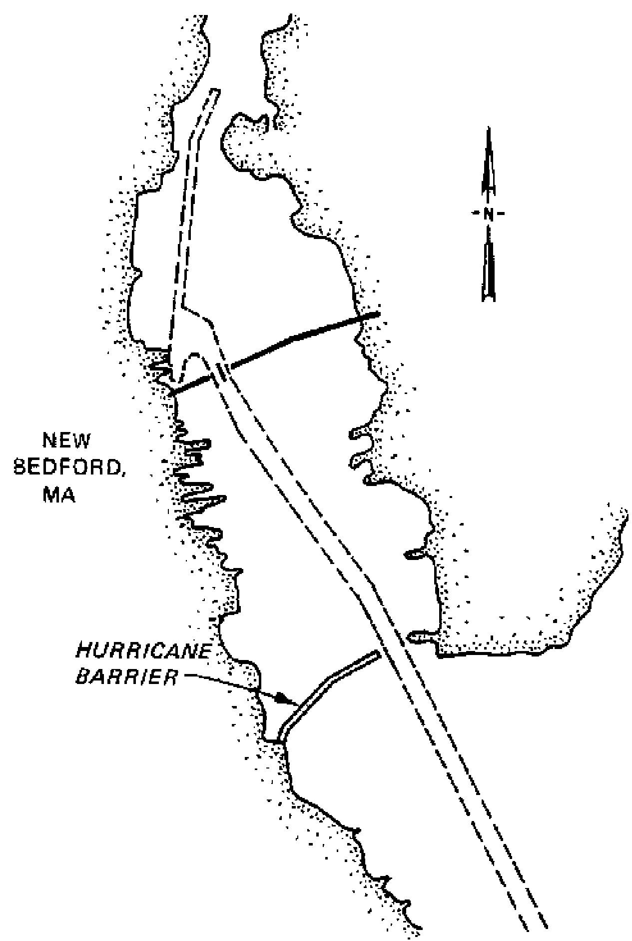


Figure 5-5. Hurricane barrier

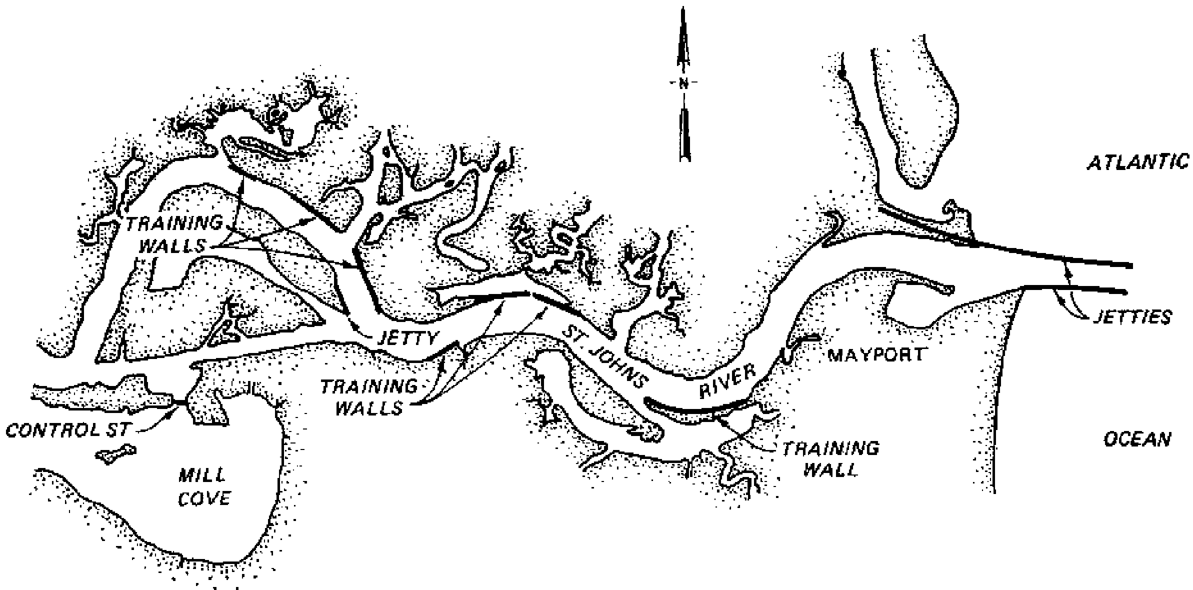


Figure 5-6. Revetments

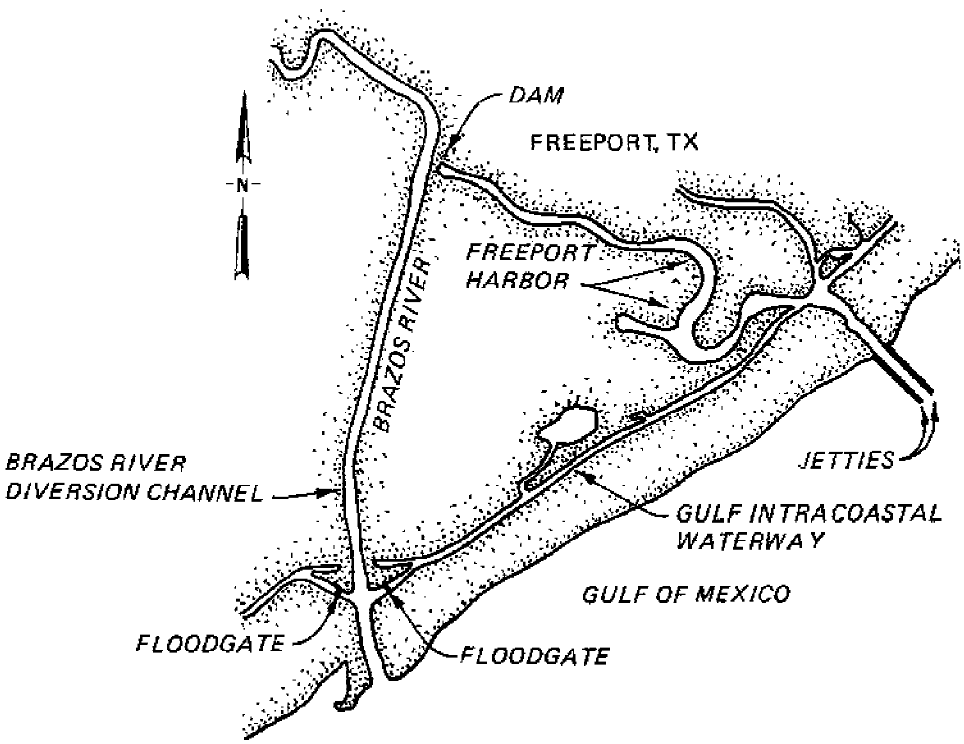


Figure 5-7. Flow diversion

g. Sediment Traps. These traps (or sediment basins) are areas in the waterway that are excavated to depths and widths equal to or greater than those of the adjacent navigation channel. They generally extend across the navigation channel although sometimes they are located in a side channel that is connected with the navigation channel. Their purpose is to reduce maintenance dredging costs by accumulating sediments within the trap rather than in scattered deposits along the channel in areas sometimes difficult to dredge or remote from disposal sites. Examples of estuarine sediment traps are given in Figure 5-8.

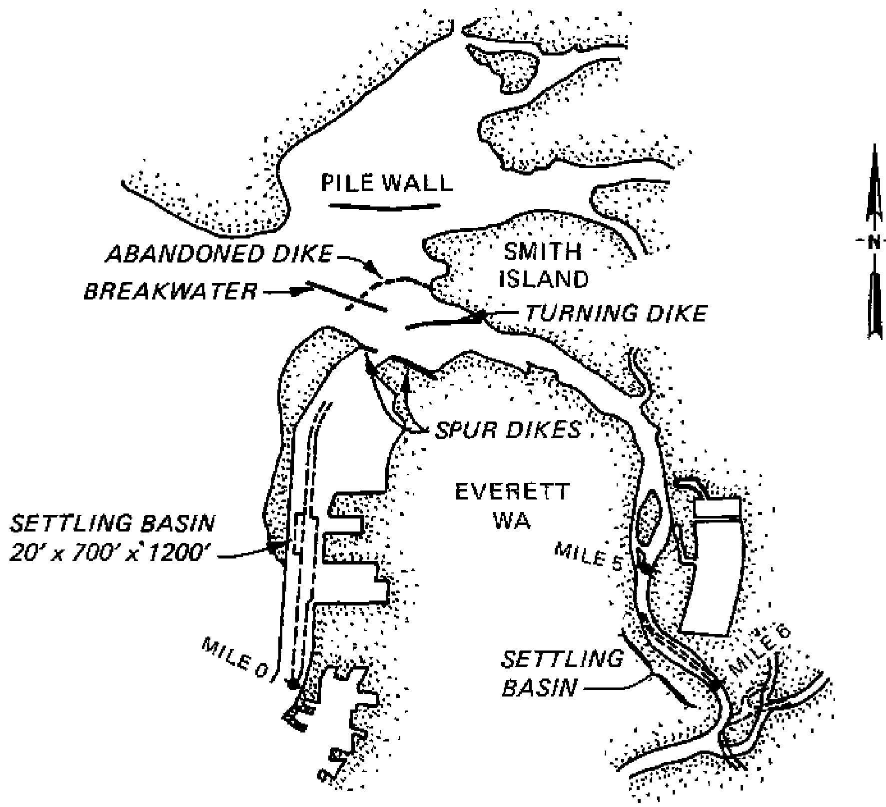


Figure 5-8. Sediment trap

Section II. Design Factors

5-3. General. In control works projects, there are usually six factors that must be addressed by hydraulic engineers during the design of the project. The impact of the project on any of these factors can control the design of the project. These factors are navigation safety, salinity, water quality, navigation channel sedimentation, general sedimentation, and flooding.

5-4. Navigation Safety. In control works projects where structures hazardous to navigation are planned adjacent to or near navigation channels, navigation safety may be a controlling factor in project design. Navigation safety may also be a controlling factor in control works projects that cause changes in currents along navigation channels, since altered current patterns can adversely impact vessel navigability. The recent development of the numerical ship/tow simulator has greatly enhanced the capability to solve existing navigation safety problems and to evaluate proposed designs to eliminate problems before construction. For detailed information on the ship/tow simulator and navigation safety, see Hewlett, Daggett, and Heltzel (1987); Huval, Comes, and Garner (1985); and Huval (1985) as well as EM 1110-2-1613.

5-5. Salinity. Freshwater supplies often are derived from the freshwater zones in the upper portions of many estuaries. The fresh water is typically used for municipal, agricultural, or industrial purposes. The development of any control works project within an estuary that might cause increased intrusion of salt into the estuary can be a threat to existing freshwater supplies. In such cases increased salinity intrusion can be a controlling factor in designing the control works project. Estuarine ecological features such as oyster beds or fish and shrimp nurseries can be significantly harmed by changes in the local salinity regime. Thus salinity can be a design factor in control works projects that alter the salinity regime in portions of an estuary.

5-6. Water Quality. Many control works projects within estuaries have the potential of changing circulation patterns and flushing rates. Flushing rates can be a controlling design factor if reduced flushing results in concentrations of dissolved or suspended materials being outside acceptable or safe limits in portions of an estuary.

5-7. Channel Sedimentation. Changes in channel sedimentation can be a controlling factor in project design if sedimentation is significantly increased or redistributed from low-cost to high-cost maintenance dredging areas.

5-8. General Sedimentation. Changes in general estuary sedimentation patterns can be a design factor in control works projects if the ecology of the estuary is threatened. For example, a benthic community could be threatened by a control works project that causes increased sedimentation or erosion in its bottom area of the estuary.

Section III. Siting of Control Works

5-9. Flooding. Control works projects within estuaries also have the potential of acting as a flood-control measure or increasing local flooding. During the project planning stage, it should be considered that the control works may function as barriers during peak hydrograph and actually create or increase localized flooding.

5-10. Estuarine Breakwaters and Jetties. The principal criteria to be observed in the layout of an estuarine breakwater are adequate depths in the area to be protected from waves; adequate depths in the approaches to the harbor entrance; and an entrance that will minimize wave action within the harbor while providing adequate clearances for navigation.

a. Design Considerations. The orientation of the entrance should be such that entrance approaches and departures can follow a course generally in the direction of the more severe waves. Safe navigation will generally require an entrance channel much wider than that of the interior channel, since control under severe wave conditions will tend to be difficult for both large and small vessels. Bar channels and entrances partly protected by jetties and training structures will require special studies of tidal currents, waves, littoral transport, and shoaling tendencies to determine the optimum relations with regard to channel width, cross section, alignment, and degree of exposure. Channel widths in entrances will have to be judiciously selected based on the analysis of conditions at each project. For detailed guidance see EM 1110-2-1613.

b. Waves. The design of the entrance for the purpose of excluding or minimizing the propagation of waves into the harbor may be accomplished by procedures described in the Shore Protection Manual (US Army Engineer Waterways Experiment Station 1984).

5-11. Salinity Barriers.

a. Dam Type. The dam type of salinity barrier should be located as far upstream as is practicable without defeating the purpose of the structure in order to interfere with navigation as little as possible. Where feasible, it should be located in a reach where vessels can approach the locks on a straight course for at least a mile before entering the guide structure. The approach reach should be free of large waves and crosscurrents, which might throw the vessel off course and make the approach to the locks difficult, see EM 1110-2-1611 and 1110-2-1613 for details of navigation channel design.

(1) Lockages will admit salt water to the upstream pool. If there are many lockages per day, it is likely that the pool will become contaminated by salt water, possibly to a greater extent than would have been the case without the barrier. There are several methods that have been employed successfully to prevent or minimize this contamination. Among these are the following: separate emptying and filling systems; a "scavenger" pool with a discharge pipeline extending through the barrier; a hinged-leaf barrier in the lock; and a pneumatic barrier. Details of these devices are given in Abraham and Burgh (1964), Wicker (1965), and Ables (1978).

(2) The barrier will impound upland discharges. During floods, the impoundment may be high enough to cause damage to shoreline installations unless the spillway is adequate to pass such discharges with a minimum of backwater effect, or unless levees are constructed along the shoreline for a sufficient distance upstream of the barrier to extend beyond the limits of such backwater effects. The normal elevation of the pool with the barrier in place may cause damages to shoreline property.

(3) The barrier should be high enough to be secure against overtopping by hurricane surges and superimposed storm waves, if it is in a locality subject to hurricanes, or it may be economical to provide lower crest elevations, depending on the uses made of the impounded water and the efficiency of

the scavenger pool that may be provided to remove the salt water.

(4) The barrier will cause important modifications of the regimen of the waterway both downstream and upstream. Downstream, the tide will rise higher and fall lower than before, the effect being greatest at the barrier and diminishing downstream. Shoreline properties will be inundated to an extent, and navigation depths decreased. Shoaling may become more serious. Upstream from the dam, the tide will be eliminated as will any existing salt-water penetration. Also the waterway above the barrier could be transformed from free flowing to an impounded pool. Typically riverflow will be maintained by operation of a control structure. An approximation of the order of magnitude of the changes may be computed by methods described in Wicker (1965), Dronkers-Schoenfeld (1955), Ippen and Harleman (1961), and McDowell and O'Connor (1977).

(5) The changes in the regimen of the waterway may be so great and of such significance that consideration should be given to conducting a numerical or physical hydraulic model study. The investigation should include consideration of the changes in the regimen downstream, the potential effects on shoaling both upstream and downstream of the barrier, the effects on pollutant accumulations upstream, the extent and concentration of salinity intrusions as a result of lockages, the design of the scavenger pool and appurtenances to prevent intrusions, and the elevations of the pool upstream at normal and at various flood discharges.

b. Submerged Sill.

(1) A second type of salinity barrier, the submerged sill, is designed to retard salinity intrusion upstream of the sill. Because the sill crest must be below the elevation of the authorized navigation channel bottom, it must be placed in a location naturally deeper than the authorized navigation channel depth. The vertical salinity structure at the sill location should be at least partially stratified, since the disruption of the bottom density current along with increased vertical mixing are the factors that make the sill effective in reducing upstream salinity intrusion. The greater the height of the sill, the greater the potential for reduced salinity intrusion upstream. The sill may be designed to be permanent or temporary. Examples of the design of both types are given in US Army Engineer District (USAED), San Francisco (1979), and Johnson, Boyd, and Keulegan (1987). The only reliable predictive techniques to investigate the effectiveness of submerged sills are physical and numerical hydraulic models.

(2) A submerged sill of the temporary type was successfully used in the Lower Mississippi River during the 1988 drought to limit saltwater intrusion. The sill, constructed of locally dredged river sands and located near river mile 63, limited the salt water approaching the freshwater intake for the city of New Orleans. The US Army Engineer District, New Orleans, designed the sill to erode away at high river discharges.

5-12. Hurricane Barriers. Hurricane barriers should be located as far downstream as is practicable, as they not only protect a larger area, but their effects on the heights of hurricane surges and on the normal regimen downstream of the barrier will be felt over lesser distances. (The fact that such structures may have important effects downstream as well as upstream should not be overlooked.) They should be located where the approaches to the gap for navigation will permit a straight sailing course for at least a mile, and where such a course will not be subject to crosscurrents and frequent severe wave action.

a. To reduce surge transmission as much as possible, the gap for ungated barriers should be as narrow and shallow as the needs of navigation will permit. The sill should be deep enough to provide adequate clearance for the vessels of the foreseeable future that will be employed in the commerce of the waterway. It should be remembered in this connection that the current velocities through the gap will undoubtedly be greater than the normal currents along the course of the waterway, and that there will be adverse effects for some distance both upstream and downstream of the gap. The width of the gap must be determined with these considerations in mind.

b. The barrier will have effects on the regimen of the waterway both upstream and downstream. Shoaling may be accelerated; the tides may rise higher and fall lower on the downstream side; the tide range may be decreased upstream; and the elevation of mean river level may be increased.

c. A satisfactory design of the navigation gap usually cannot be accomplished without benefit of a numerical or physical hydraulic model study and a ship simulator study. From these studies, the best arrangement and location for the barrier as well as for the navigation gap can be determined. These studies will also provide reliable information on the effects of the barrier, with gaps of various dimensions installed, on the regimen of the waterway upstream and downstream, as well as on the navigability of the gaps tested. Tests including a range of upland discharges should be run in the hydraulic model to determine the backwater effects of the barrier.

d. The barrier should be high enough to protect against the design hurricane surge. Surge heights may be computed according to the procedures described in EM 1110-2-1412.

5-13. Training Dikes. In reaches of the waterway where it is necessary to locate the navigation channel elsewhere than in the natural thalweg, the currents will be at an angle to the channel rather than parallel with it, and shoaling is likely to be heavy. It may be possible to force the currents into a course that parallels the navigation channel rather than the thalweg (which then will shoal and the navigation channel will become the new location of the thalweg) by constructing dikes. These may be either parallel with the navigation channel, or consist of a system of spur dikes extending out from the shore into the current that is to be diverted. The effects of longitudinal dikes on the regimen of the waterway are generally local. As spur dikes necessarily cause a constriction, they may have important effects both downstream and upstream possibly for considerable distances. Longitudinal dikes also cause a constriction if they are connected to shore at one or both ends.

a. The location, layout, and orientation of training dikes, as well as scour problems around the structure, can be determined best by use of a physical or numerical hydraulic model. Without the use of a model, there will be little assurance that a satisfactory design has been obtained until the structures have been built and their action observed. These structures are expensive, and it is necessary to have the best obtainable assurance that they will have the desired effects on the regimen of the waterway.

b. The clearance between the edge of the channel and the ends of spur dikes or a longitudinal dike must be adequate to assure safe navigation. Vessels get off course, particularly during low visibility, and they may suffer damage if they strike the dike. It is desirable to avoid locating dikes adjacent to curves or turns in the channel, as vessels are more likely to stray from the channel in negotiating the turn. It is important to keep in mind that the existing navigation channel may not be the ultimate configuration or depth; therefore, consideration should be given to so locating the dike to permit an improved channel to be excavated with the dike still at an adequate distance from its edge. Adequacy of clearance between the edge of the channel and training works varies from waterway to waterway and reach to reach. Channel design procedures for navigation safety are discussed in ER 1110-2-1404 and EM 1110-2-1613.

5-14. Revetments. Revetment of the banks of tidal waterways is usually necessary where the width is only slightly greater than the width of the navigation channel, and where wave wash due to passing vessels will cause erosion. If a bank needs protection from erosion by revetment, it is essential that the bank be reveted to as low a level as possible and that undercutting be prevented. Revetments are usually expensive to construct and require periodic maintenance. Design considerations for revetments are given in US Army Engineer Waterways Experiment Station (1984), McDowell and O'Connor (1977), Peterson (1986), and EM 1110-2-1601.

5-15. Diversion Works. Upland discharges of sediment-laden fresh water into the tidal waterway often results in heavy shoaling. Under favorable circumstances, it may be possible to divert the principal upland discharge from an estuary having important navigation channels that are subject to heavy shoaling into a nearby waterway where shoaling is inconsequential.

a. The water in the estuary from which the freshwater discharges are to be diverted will become more saline depending upon the fraction of fresh water removed. If the waters of the estuary are used for domestic, agricultural, or industrial purposes, the diversion will have serious effects on the local economy. It may be necessary to provide a substitute source of supply as part of the diversion scheme. As diversion may either improve or worsen water quality conditions in the waterway, the effect on water quality should be intensely studied. Similarly, the diversion will cause the waterway receiving the diversion to be less saline than before; it will accelerate the currents, possibly causing scour of the bed and banks; and it may cause shoaling in downstream reaches. The decrease in salinity may be detrimental to a seafood industry, the sediment may damage nearby beaches, and the shoaling may be harmful to the existing navigation in the waterway receiving the diverted waters. Erosion of the banks in the receiving waterway may cause significant property damages.

b. The diversion works consist of a dam to close the estuary from normal and most flood discharges, and a canal to convey the diverted waters to a neighboring stream or to the sea. If the canal is of considerable length, it may be found to be infeasible to provide a cross section adequate to discharge floods greater than some magnitude to be defined by economic analyses. The factors in such economic analyses are the costs of diversion works required for flows of the several magnitudes being considered and the adverse effects of permitting flows larger than each of these to be discharged to sea through the estuary. Sediment transport capacity should also be considered in the design of the diversion channel.

5-16. Sediment Traps. The purpose of a sediment trap is to manage sedimentation processes so that sediment can be dredged in the most cost-effective manner. Properly designed traps allow for the removal of sediment at locations that result in the least overall maintenance dredging costs. The critical factor for trap effectiveness is that the material trapped would have otherwise deposited somewhere within the project boundaries. If a large percent of material trapped would otherwise be transported through the estuary or be deposited in areas outside the project limits, the trap is ineffective and should not be maintained as a sediment trap.

a. If a physical hydraulic model of the estuary is available, much of the trial and error involved in developing an effective trap can be done in the model in a few weeks rather than in the field over a period of years. In the past, WES has conducted sediment trap tests in physical models, such as those described in Dronkers-Schoenfeld (1955), Ippen and Harleman (1961), Johnson, Boyd, and Keulegan (1987), McDowell and O'Connor (1977), Peterson (1986), Trawle and Boland (1979), and USAED, San Francisco (1979).

b. Sediment traps can now be investigated with numerical sediment transport models, a modeling tool that has only recently become available. In a numerical modeling effort, the investigation of sediment traps can be part of an overall evaluation of shoaling under proposed conditions. An example of this type of investigation is given in Granat (1987).

c. The investigation of sediment traps in an estuary using either a physical model or a numerical sediment transport model is not inexpensive. However, these are the principal tools available to address the problem in a complex system such as a tidal estuary with a reasonable degree of confidence. The investment in models can be repaid by correction of costly design deficiencies or identification of more workable solutions.

Section IV. Maintenance Dredging

5-17. Dredging Plant. The selection of dredging plant and the operational procedures to be employed are based on the in situ characteristics of the materials to be removed, traffic conditions in the waterway, the distances to disposal areas, the exposure to waves that may disrupt operations or damage equipment, availability of dredging plant, and environmental considerations. Where there are alternatives, the selection should be determined on the basis of the least cost of producing the desired channel (not the lowest unit cost of dredging) with a method that is environmentally acceptable. The cost of proper disposal of the dredged material, to the end that the material once dredged cannot return to the shoal, should be considered. On the other hand, it is conceivable that some other method is competent to remove very large volumes of material at very low costs, and even if a large portion of the material returns to the shoal, the depths provided are obtained at lower annual cost than would be experienced if the dredged material were meticulously removed from the waterway. The choice should always be for the method that produces a satisfactory channel at the least annual cost and environmental damage; the cost per cubic yard dredged is not in itself always a complete basis for selection of plant and methods for dredging.

a. When the work is to be done by contract rather than by Government plant and labor, it is rarely possible to specify the kind of plant to be employed, but the specifications will provide for the end results desired, require that plant move aside for traffic, and specify rehandling and disposal requirements. In situations where careful disposal of the dredged material is necessary to obtain a satisfactory channel at the least cost, this will be required in the specifications regardless of whether the plant of some prospective bidders will have more difficulty complying with the specifications. Environmental requirements may restrict the use of certain dredging equipment at a specific project. The conditions at the disposal area may also restrict certain equipment, i.e., if settling rates are not adequate, disposal may be limited to mechanical methods.

b. If unconsolidated or weakly consolidated deposits are to be dredged, dipper, bucket, pipeline, hopper, or sidecasting dredges may be used. Where the deposits include boulders, it may be necessary to use dipper or bucket dredges unless the boulders can be buried by overdigging with the suction head or cutterhead close to the boulder and causing it to topple into the hole. For new-work dredging, as contrasted with maintenance dredging, consolidated sand or silt or clayey materials may be encountered. For dredging such materials, the pipeline dredge with cutterhead rather than a suction head type of dredge will generally remove the material more economically. In rock or other strongly consolidated materials, it may be necessary to employ dipper or bucket dredges, and drilling and blasting may be required. Where the material is such that any of the conventional dredges can remove it effectively, the choice between them will be based on traffic density, distance to disposal areas, depth of cut, and exposure to wave action. If traffic density is so great that operations will be interrupted to an extent that results in costs being increased beyond those of plants subject to less interference, the latter will be selected. Similar considerations will govern selection of plant in locations where significant wave action is likely. Distance to acceptable disposal areas is a factor in the cost of operations for all types of dredges, but it is likely to be most significant for pipeline dredges. When the length of pipeline to reach a given disposal area results in costs that make dipper, bucket, or hopper dredges in conjunction with remaining operations more economic, the pipeline dredge no longer is the best tool for the operation. Where the depth of cut is small in relation to the plant capability, it is usually found that the controlling factor in the cost of dipper, bucket, or pipeline dredges is the time involved in advancing the dredge into the deposit rather than the effort to remove the material. Hopper and sidecasting dredges can more effectively cope with thin cuts, and may be the most economic dredge type in these instances. For further information, EM 1110-2-5025 as well as Herbich (1975) and Huston (1970) should be consulted.

5-18. Advance Maintenance Dredging. A typical dredged channel with no provision for advance maintenance dredging is shown in Figure 5-9. The basic specifications for the dredged dimensions are the authorized or project

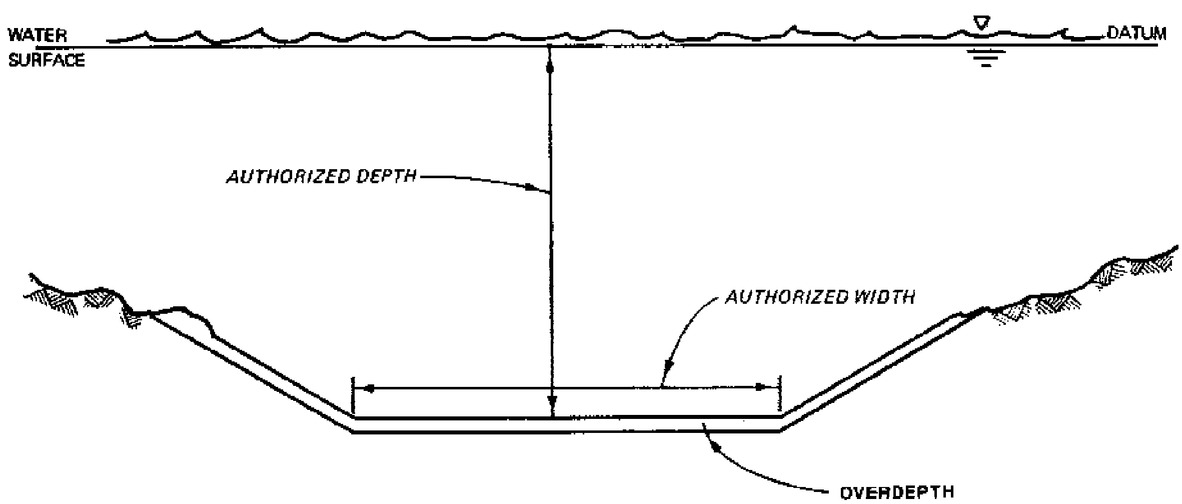


Figure 5-9. Typical dredged channel cross section without advance maintenance

depth, the authorized or project width, the side slopes, and the overdepth for providing channel dimensions until the next dredging cycle. The authorized depths and widths are those channel dimensions authorized by Congress. If, for some reason, it becomes unnecessary to maintain a channel at authorized dimensions, the channel is maintained only to the economic dimensions, which are less than authorized.

a. A typical project with advance maintenance dredging included is shown in Figure 5-10. Typical amounts of advance maintenance vary from 1 to 10 feet. A listing of Corps projects using advance maintenance along with specifications is provided in Trawle and Boyd (1978). The primary objective

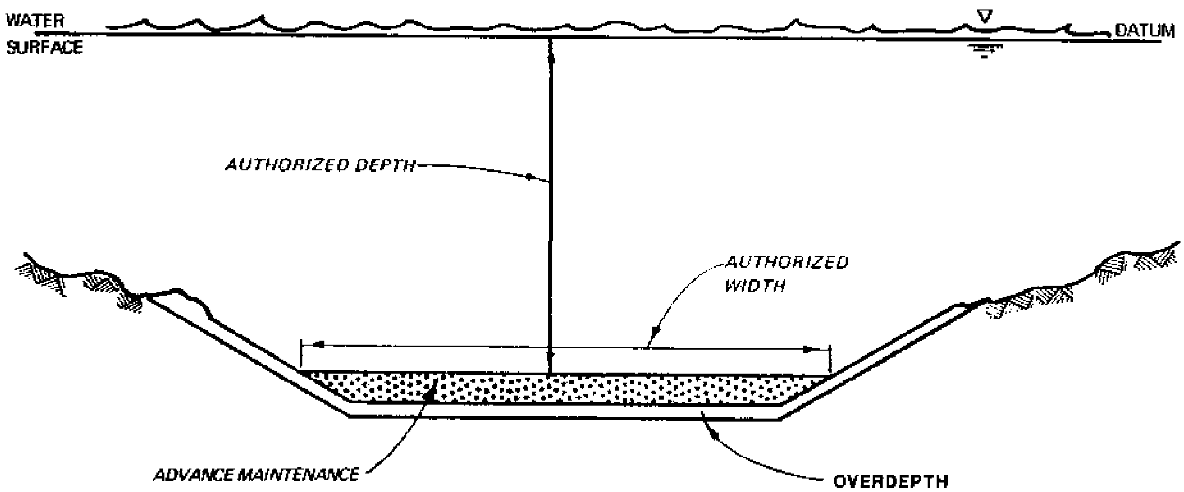


Figure 5-10. Typical channel cross sections with overdepth form of advance maintenance included

of advance maintenance dredging is to reduce the required dredging frequency, which can result in reduced overall maintenance dredging costs. A second objective can be to increase the percentage of time that a project is at project dimensions.

b. Advance maintenance dredging should not be confused with allowable dredging overdepth. The allowable dredging overdepth, usually 1 or 2 feet, is simply a margin for error that allows the dredging contractor to be paid for material dredged within a specified depth (usually 1 or 2 feet) below the required depth.

c. The key factor in advance maintenance effectiveness is the relation between depth and sedimentation rates. If increased depth causes no increase or only a slight increase in sedimentation rates, then advance maintenance can be very effective, since the required dredging frequency can be significantly reduced with little or no increase in overall maintenance dredging volumes. If, however, increased depth causes dramatic increases in the sedimentation rates, advance maintenance is probably not an effective technique, since the required dredging frequency will not be reduced significantly and overall maintenance dredging volumes can increase greatly. For more information on advance maintenance design considerations, see Trawle (1981), Berger and Boyd (1985), and Gelbert and Kean (1987).

5-19. Agitation Dredging. Agitation dredging is the removal of bottom material from a selected area by using equipment to suspend it temporarily in the water column and allowing currents to carry it away. This definition means that agitation of the bottom material is accomplished by some type of equipment and that the main purpose of the dredging equipment is to raise bottom material into the water column. Currents are used to move the material in the water column. Natural tidal currents are usually the mechanism for transport, although they may be augmented by currents generated by the agitation equipment. Since currents are a necessary part of the agitation dredging process, a good understanding of local hydrodynamics is essential for a successful operation. If the material is suspended but shortly redeposits in the same area, only agitation (not agitation dredging) has occurred. By definition, agitation dredging includes transport of material away from the problem area. However, care should be taken to assure that the agitated material does not redeposit in nearby navigational facilities. Agitation dredging can be accomplished using a wide variety of equipment. Some of the equipment that has been applied in the field to perform agitation dredging will now be discussed.

a. Hopper Dredges. Hopper dredge agitation is produced by hopper overflow. The success of this type of agitation dredging hinges on two factors:

(1) The sediments should be of such character so that the hopper dredge can easily raise bottom materials to the surface.

(2) Currents should be sufficient to remove agitated material from the navigation channel. Detailed discussions on hopper dredge agitation dredging are given in Richardson (1984), USAED, Philadelphia (1969), and USAED, New Orleans (1973).

b. Propwash. Successful agitation dredging operations by propwash tend to have the following characteristics:

(1) The propwash vessel is fitted with an adjustable deflector device and convenient anchoring system.

(2) Shoaling is localized and well-defined in moderate water depths.

(3) Shoal material is fine, easily erodible, and uncompacted.

(4) Natural currents augment the agitation and transport process.

(5) Wave action is not severe enough to cause a hazard to the dredging plant or render the operation ineffective.

Detailed discussions on propwash agitation dredging are given in Richardson (1984), Slotta et al. (1974), Bechly (1975), and Burke and Wyall (1980).

5-20. Vertical Mixers and Air Bubblers. Vertical mixers such as the Helixor and Ventra Vac units and air bubblers are grouped together because they claim the same basic operating principle: by releasing compressed air near the bottom, the devices induce currents in the water column rising from the bottom to the surface. These currents are supposed to carry with them sediment from the bottom and near-bottom, at least part of which is to be resuspended by horizontal currents feeding the rising vertical currents.

a. In theory, such devices should work by maintaining sediment in suspension until natural currents can flush it away. In practice, however, no successful field results have been reported to date. There appear to be some fundamental problems with how the operating principle of such devices relates to the objective in agitation dredging.

b. There is no question that such devices as the Helixor, Ventra Vac, and air bubblers can induce significant rising vertical currents extending to the water surface. In agitation dredging with these devices, however, the horizontal flow patterns and velocities are also important, since horizontal flow is what brings sediment to the vertical plume. Investigators have shown that horizontal currents into line source air bubblers are relatively weak, the zone of influence of such currents is limited, and exponential power increases are required to increase horizontal flow into the bubble plume. A detailed discussion on the use of these devices in agitation dredging is Richardson (1984) and DeNekker and Knol (1968).

5-21. Rakes and Drag Beams. Rakes, drag beams, and similar devices work by being pulled over the bottom, mechanically loosening the bottom material and raising it slightly in the water column. Although crude, they can be effective in areas with cemented, cohesive, or consolidated sediments; and they require no special equipment other than a vessel to pull them. In shallower water and with a large enough vessel, propwash may help in the agitation process as well. The draghead of a trailing suction hopper dredge acts as a rake to some degree as it is pulled along the bottom, since not all of the material it loosens is drawn into the suction tube. Since rakes and drag beams produce no currents of their own and since they do not resuspend material as much as loosen it, they must be used in conjunction with natural currents strong enough to transport the loosened material away from the shoaling site. Drag beams have been used to displace material above required depth and move it into areas that have been overdredged. One possible way for helping the dragging process is by the use of air bubblers. Another way would be to deflect the propwash of the towing vessel downward toward the dragging device. A combination of the three--dragging, air bubbler, and propwash--might prove the most effective of all, especially when the towing vessel moves into a current so maximum use is made of the propwash. A detailed discussion of agitation dredging using rakes and drag beams is given in Richardson (1984).

5-22. Water Jets. Water jets for agitation dredging operate on the same fundamental principle as propwash agitation with the following main differences:

a. Water jets can be grouped in any arrangement desired.

b. Streams issuing from the jets usually originate close to or on the bottom rather than the surface.

c. Water jets are usually used in fixed locations.

d. Water jets are usually intended for frequent operation to prevent large shoaling accumulations, whereas propwash is a remedial measure to remove shoal deposits. Because of the last point mentioned, water jet installations lend themselves to automatic operation. They may also have difficulty removing larger amounts of shoaling that might accumulate during periods of non-operation. Detailed discussions on the use of water jets in agitation dredging are given in Richardson (1984), Ali and Halliwell (1980), and Barlard (1980).

Section V. Case Histories

5-23. Description. A case history that describes the hydraulic processes that occur in an estuary as well as provides the history of development of that estuary is an important item when modifications to any estuary are being considered. The case history should be developed early on as a guide for scoping future design studies. Such a document should include the discussion of any changes in hydraulic behavior observed as the result of past modifications by either man or nature. This document will provide valuable information that should be summarized in subsequent design documents.

5-24. Contents. Case histories should include the following information:

a. History of project authorization and development.

b. Description of existing projects.

c. Project-related problems.

d. Facts and data bearing on the problem.

e. Description of modeling (physical or numerical) studies.

f. Analysis of problems.

g. Lessons learned.

5-25. Lessons Learned. A discussion of lessons learned from Corps navigation projects, developed by the Committee on Tidal Hydraulics (CTH), is given in Appendix E.

5-26. Physical Model Studies. A list of the various tidal hydraulic model investigations that have been constructed and operated by WES is given in Appendix F.